

# **Exploitation of Environmental Complexity in Shallow Water Acoustic Data Communications**

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## **LONG-TERM GOALS**

Conduct feasibility experiments and associated algorithm design to explore how complexity of the shallow water acoustic environment can be used advantageously in acoustic data communications.

## **OBJECTIVES**

Exploit environmental complexity through both real and synthetic aperture spatial processing to mitigate multipath-related fading and intersymbol interference in acoustic data communications.

## **APPROACH**

The origin of this research is our experience with carrying out ocean acoustic time reversal experiments over a broad range of frequencies. Through a series of experiments conducted jointly between MPL and the NATO Undersea Research Centre (NURC), we have demonstrated that complexity of the ocean environment fundamentally is advantageous and facilitates rather than inhibits the resolution of physical processes, detection of targets, and acoustic telemetry of data. Furthermore, the time reversal experiments have illustrated that the ocean maintains a far greater inherent coherence than previously has been thought possible. Thus, the overall goal of this research is to take advantage of the self-adaptive nature of the complex ocean environment and learn how to exploit fluctuations, scattering, and variability.

### *Multiple-Input / Multiple-Output (MIMO) Acoustic Data Communications*

The active time-reversal approach directly achieves spatial diversity through use of an array of sources. Source array diversity can be complemented with receive array diversity to enable transmitting independent communication sequences in parallel thus increasing the total data rate through the channel. The source array and receive array pair implements a multiple-input/multiple-output (MIMO) system. Although not optimized for overall communication system performance, the time-reversal approach is straightforward, results in relatively compact two-way channel responses, and yields high SNR at the focal depths of the communication sequences. Furthermore, the simple strategy of post-processing the communication sequence observed at a focal depth with a single-channel equalizer can prove effective.

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Here our objective is to exploit the dynamic propagation complexity arising from source-receiver motion to achieve the equivalent of an extended physical aperture with a single source-receiver pair. The underlying approach involves using distributed aperture time reversal to compensate for channel dispersion and the resulting problem of intersymbol interference (ISI). In order to fully understand medium complexity in the role of enhancing construction of the synthetic aperture, the focal region structure and temporal sidelobe characteristics obtained with a synthetic aperture array in the ocean medium needs to be explored. In addition, since we typically record transmissions on a vertical receive array, a direct comparison can be made between the synthetic aperture approach to a single receive array element and passive time reversal where a single transmission is received on multiple receive array elements – as well as combinations of the two. Essentially, we will be investigating how the medium complexity maps into spatial diversity between the source and receive array.

## **WORK COMPLETED**

Experimental data collected during a joint experiment with the NATO Undersea Research Centre (NURC) has demonstrated the feasibility of a MIMO acoustic data communications approach using time reversal. Simultaneous transmissions to three depths using QPSK and two depths using 8-QAM were achieved [3].

## **RESULTS**

In active time reversal, the channel response from each source in a source array to a desired focal point in the ocean is obtained, time reversed, and retransmitted simultaneously from all sources. In the context of acoustic data communications, the time reversed channel response is used as the symbol waveform onto which the data bits are phase (and amplitude in the case of QAM) encoded. Although the symbols are heavily overlapped at the source array, they compress nicely in both time and space at the focal point [1].

During FAF-03 (Focused Acoustic Fields Experiment 2003), a new focusing procedure was demonstrated which does not require deployment of a probe source at the desired focal point [2]. Instead, a radio-telemetered vertical receive array (VRA) effectively provides the equivalent waveguide response required for time reversal (see Fig. 1). The channel response from a probe source to the source-receive array (SRA) can be obtained by a single element of the VRA at the probe source location receiving pings from each element of the SRA transmitted sequentially. The multiplexed reception at the VRA element is made available via radio telemetry. After demultiplexing, the multiple channel responses (one for each SRA element) are time reversed and retransmitted by the SRA yielding a focus at the equivalent probe source location. This procedure then can be generalized to focus SRA transmissions simultaneously at any of the depths of the VRA elements.

The new focusing procedure facilitated demonstrating the simultaneous transmission of independent communication sequences from the SRA to multiple depths at 3.5 kHz in 105 m deep water with an 8.6 km separation between the SRA and VRA (see Fig. 2) [3]. This MIMO approach has the advantage of both increasing the overall communication bit rate along with high SNR at the focal depths thus resulting in low BER (bit error rate). In addition to these 8-QAM results, simultaneous QPSK transmissions to both two and three depths also were demonstrated [3].

## **IMPACT / APPLICATIONS**

Acoustic data communications is of broad interest for the retrieval of environmental data from in situ sensors, the exchange of data and control information between AUVs (autonomous undersea vehicles) and other sensing systems and relay nodes (e.g. surface buoys), and submarine communications.

## **RELATED PROJECTS**

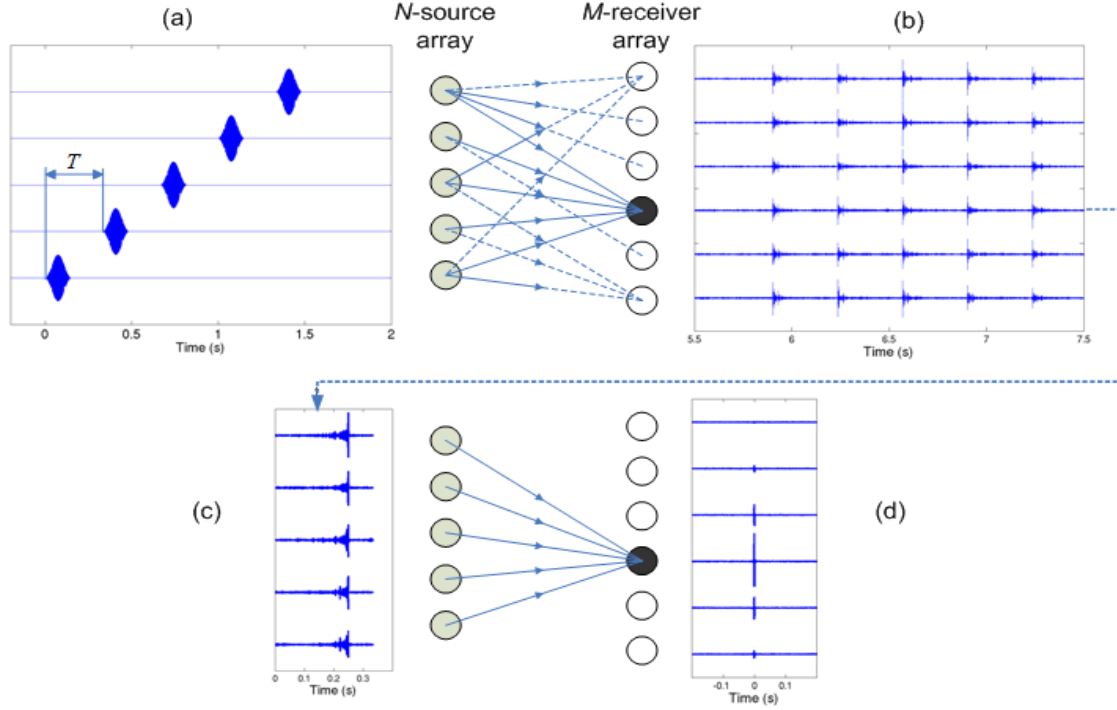
This project is one of several sponsored by ONR Code 321OA and NRL which are exploring various aspects of high frequency channel characterization with specific applications to acoustic data communications and includes experimental work with the NATO Undersea Research Centre (NURC) and the recent KauaiEx (2003) and Makai (2005) experiments.

## **PUBLICATIONS**

[1] G.F. Edelmann, H.C. Song, S. Kim, W.S. Hodgkiss, W.A. Kuperman, and T. Akal, "Underwater acoustic communications using time reversal," J. Oceanic Engr. (in press, 2005). [in press, refereed]

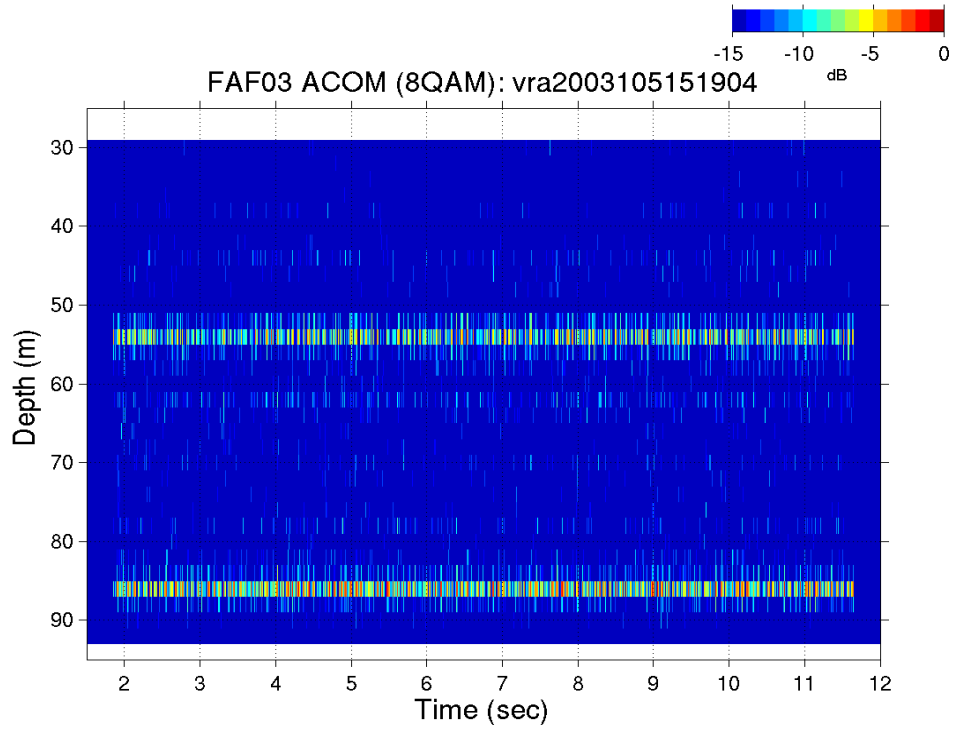
[2] P. Roux, W.A. Kuperman, W.S. Hodgkiss, H.C. Song, T. Akal, and M. Stevenson, "A non-reciprocal implementation of time reversal in the ocean," J. Acoust. Soc. Am. 116(2): 1009-1015 (2004). [published, refereed]

[3] H.C. Song, R. Roux, W.S. Hodgkiss, W.A. Kuperman, T. Akal, and M. Stevenson, "Multiple-input/multiple-output coherent time reversal communications in a shallow water acoustic channel," IEEE J. Oceanic Engr. (in press, 2005). [in press, refereed]

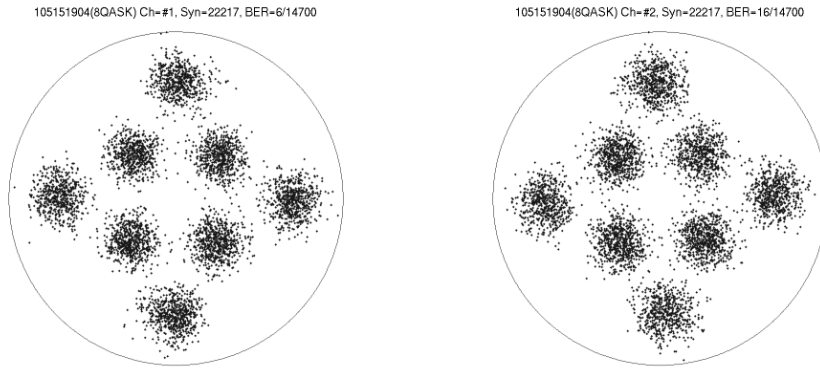


**Figure 1. Illustration of the focusing procedure. (a) Transmit pings sequentially from each element of the source-receive array (SRA). (b) Receive these transmissions at a single element of the vertical receive array (VRA). Make available the multiplexed reception at the VRA element via radio telemetry. (c) After demultiplexing, time reverse and retransmit simultaneously from the SRA the multiple waveguide channel responses (one for each SRA element). (d) The retransmission focuses at the VRA element from which the channel responses were extracted.**

(a)



(b)



**Figure 2. Multiple-depth acoustic data communications during FAF-03. The SRA and VRA were separated by 8.6 km in 105 m deep water.**

**(a) Received time series at the VRA showing high-SNR focused receptions at two depths.**

**(b) Scatter plots for each of the two independent 8-QAM communication sequences.**